Agriculture Canada

Research Branch | Direction générale de la recherche

Technical Bulletin 1986-1E

Concepts and classification of Gleysolic soils in Canada

986
RESEARCH RECHERCHES

The map on the cover has dots representing Agriculture Canada research establishments.

ONE HUNDRED YEARS OF PROGRESS

The year 1986 is the centennial of the Research Branch, Agriculture Canada.

On 2 June 1886, *The Experimental Farm Station Act* received Royal Assent. The passage of this legislation marked the creation of the first five experimental farms located at Nappan, Nova Scotia; Ottawa, Ontario; Brandon, Manitoba; Indian Head, Saskatchewan (then called the North-West Territories); and Agassiz, British Columbia. From this beginning has grown the current system of over forty research establishments that stretch from St. John's West, Newfoundland, to Saanichton, British Columbia.

The original experimental farms were established to serve the farming community and assist the Canadian agricultural industry during its early development. Today, the Research Branch continues to search for new technology that will ensure the development and maintenance of a competitive agri-food industry.

Research programs focus on soil management, crop and animal productivity, protection and resource utilization, biotechnology, and food processing and quality.

Concepts and classification of Gleysolic soils in Canada

J. A. McKEAGUE, C. WANG, C. TARNOCAI, and J.A. SHIELDS
Land Resource Research Institute
Ottawa, Ontario

LRRI Contribution No. 85-08

Research Branch
Agriculture Canada
1986

Copies of this publication are available from:
Director
Land Resource Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario
K1A 0C6

Produced by Research Program Service

Cat. No. A54-8/1986-1E
ISBN 0-662-14526-7

Également disponible en français sous le titre
Revue des concepts et classification des sols gleysoliques au Canada

Contents

ABSTRACT

Developments in concepts and classification of Gleysolic soils in Canada throughout this century emanated from increasing knowledge of soils in this country and elsewhere. Some of the current problems in classifying these soils are shown to be due to a tendency to insist that soil taxonomy should be compatible with the current soil water regime. Separating soil water regime from soil taxonomy at the higher levels conveys additional information. Though more elegant bases of criteria were sought, soil color is still the most useful known property for differentiating Gleysolic soils from others. Results of recent proposals for fine-tuning the criteria of the Gleysolic order are incorporated into a revised draft of the order. Further work is required to resolve a few outstanding problems but the need for research on Gleysolic soils is minor in relation to that on other soil problems. The revised system requires testing in all regions and documentation of problems that arise.

RÉSUMÉ

L'évolution des façons de concevoir et de classifier les sols gleysoliques au Canada depuis le début du siècle a suivi les progrès de nos connaissances à leur sujet, tant ici qu'à l'étranger. Certains des problèmes courants éprouvés dans la classification de ces sols découlent du parti pris voulant que la systématique des sols doive être compatible avec leur régime hydrique. Or la séparation des deux aux niveaux supérieurs est plus instructive. Bien qu'on ait cherché une gamme de critères plus perfectionnée, la couleur du sol demeure encore la propriété la plus utile qu'on connaisse pour distinguer les sols gleysoliques des autres. Les résultats de propositions récentes en vue d'améliorer les critères de l'ordre gleysolique sont intégrés à un projet de révision de cet ordre. Du travail supplémentaire s'impose pour résoudre un petit nombre de problèmes encore en suspens, mais les besoins de recherches sur les sols gleysoliques sont mineurs en regard de ceux découlant des autres problèmes pédologiques. Le système révisé nécessite des essais dans toutes les régions et la description des problèmes qui surviennent.

INTRODUCTION

Dissatisfaction with the criteria for distinguishing soils of the Gleysolic order have been expressed at soil survey meetings since the Canadian system of soil classification was published (Canada Department of Agriculture, 1970). For example, in 1970, the addition of a Pseudogleysol great group was among the proposals (McKeague, 1970) and in 1973, nine proposals for change were discussed (Smith, 1973). At recent meetings of the Expert Committee on Soil Survey (ECSS) development of improved criteria for soils of the Gleysolic order was assigned a high priority in research on soil classification (Day, ed. 1979, 1980, 1981). Such research was initiated in 1981 and the proposals developed were considered at the ECSS meeting in 1984 (Tarnocai, 1985). Some of them were accepted but the need for further specific work was indicated. The persistence of the problem of defining adequate criteria for the differentiation of Gleysolic soils suggests its complexity.

The purposes of this report are to review briefly the developments in concepts and classification of Gleysolic soils in Canada, to summarize results of research on the problem, to indicate the rationale behind current proposals for changes in classification, to redraft the chapter on the Gleysolic order on the basis of proposals accepted at the last ECSS meeting (Tarnocai, 1985), and to comment on further requirements for research.

REVIEW OF CONCEPTS AND CLASSIFICATION OF GLEYSOLIC SOILS

Developments Prior to 1963

Soils currently classified as Gleysolic have been distinguished in soil mapping and classification since soil survey began in Canada. In the earliest survey in Ontario "drainage" was a series criterion (Ruhnke, 1926). These series, lowest category in a three category system, were broadly defined; only nine were identified in southern Ontario. Ellis (1932) included a hydromorphic associate at the third level from the top in his four category field classification system. According to him, characteristics of extreme hydromorphism were a glei horizon, reduction processes and mottled subsoil colors. He did not define a precise limit between hydromorphic soils and the better-drained associate (phytohydromorphic) but the decision was to be based on soil morphology. Ellis (1932) wrote, "Although associates are determined very largely by relief or position, they must not be mapped on position but on the basis of the morphological features expressed within the soil profile,".

In the first proposed national system of soil classification (Stobbe, 1945), wet soils were differentiated in the fourth category of the seven-category system. No specific criteria were given in this general field classification system. Stobbe (1955) outlined the first "natural" or "taxonomic" system of soil classification in Canada It included Gleysolic soils as one of the seven classes in the highest (sixth) category (order). The class was defined as follows: "Soils with peaty (less than 12") or mineral surface high in organic matter, or both, and dull colored subsoils (with chroma of 1 or less or not higher than the parent material), and/or with brighter colored prominent mottles". The definition was centered on soil

drained soils developed under various climatic and vegetative conditions in the presence of high or strongly fluctuating water table". Classes in categories five (great group) and four (subgroup) were named but not defined.

The spelling changed but the definition of the Gleysolic order remained essentially the same for the next several years (Ehrlich 1958, 1960). Though the criteria were not specific, the concept of Gleysolic soils included their association with periodic or permanent saturation with water and reduction. Mapping of Gleysolic soil, however, was probably based at least as much on vegetation and position in the landscape as on soil properties. Few, if any, specific data were available on the magnitude of water table fluctuations and of oxidation-reduction potentials in soils of Canada. Though mottling was noted in soil descriptions, few detailed descriptions of the abundance, size and shape of mottles and the color of mottles and matrix had been done in Canada.

Developments From 1963 to 1981

The more precise color criteria of Gleysolic soils introduced in 1963 (Ehrlich, 1963) were based upon similar criteria for Aqu-suborders outlined in the 7th Approximation (Soil Survey Staff, 1960). These criteria based upon low chromas of the soil matrix and prominent mottles had not been tested in Canada. Gleyed subgroups of other orders were defined only in general terms in Canada.

The color criteria for Gleysolic soils have remained essentially constant since 1963. The only basic changes are: gley colors and/or prominent mottling were required to occur within 50 cm of the mineral surface in 1968 and prominent gray or brown mottles in materials of reddish color was added as a criterion in 1978 (Canada Soil Survey Committee, CSSC, 1978). Some changes in definition of the order were introduced in 1968 when "under reducing conditions" was mentioned in addition to saturation with water (McKeague, 1968). An oxidation - reduction potential of less than 100 mv within the upper 50 cm was also mentioned as a possible criterion. The emphasis on reduction was justified on the grounds that soils could be saturated with water for a month or more without being depleted of oxygen and gleyed. Wet soils on slopes (moving aerated water) and soils saturated only when the temperature is close to 0°C were given as examples.

Suggestions for changes in the Gleysolic order (McKeague 1970) and (Smith, 1973) show the continuing dissatisfaction with differentiation of classes within the order, definitions and criteria. For example, the question of whether to split groundwater gleys from psueudogleys has been raised frequently. The inadequacy of criteria for distinguishing gleyed subgroups from Gleysolic soils is a persistent topic; regional criteria have been considered but dropped in favor of maintaining a national system (Smith, 1973). The current system (CSSC, 1978) is somewhat more specific than previous versions in indicating limits between Gleysolic soils and soils of other orders but the basic color criteria remain unchanged with the exception for reddish materials mentioned in the previous paragraph. Perhaps the major change is the attempt to state the rationale of the system and the associated

implications to Gleysolic soil classification.

Confusion has resulted from a contradiction between a general statement of the criteria and the specific criteria. The general statement on page 69 (CSSC, 1978) is: "Gleysolic soils have within 50 cm of the mineral surface either matrix colors of low chroma or distinct to prominent mottles of high chroma,". The specific criteria, however, require within 50 cm chromas of 1 or less without mottles or chromas of up to 3, depending on hue, accompanied by prominent mottles. The consequences of this contradiction can be seen from the following examples. Suppose that a horizon at a depth of 20-50 cm has a matrix color of 10YR 4/3 with mottles 10YR 4/6. This would be diagnostic of a Gleysolic soil according to the general statement quoted; distinct mottles occur within 50 cm. Application of the specific criteria would exclude the soil from the Gleysolic order; matrix chroma is too high and the mottles are not prominent. The specific criteria were intended but the statement of Gleysolic order criteria is ambiguous.

Distinct and prominent mottles are defined in slightly revised terms from Day (1983) as follows:

Distinct mottles commonly have the same hue as that of the soil matrix but differ by 2 to 4 units of chroma or 3 to 4 units of value; or, they may differ from the matrix color by 2.5 units (1 Munsell page) of hue but by no more than 1 unit of chroma or 2 units of value.

Prominent mottles that have medium chroma and value commonly differ from the soil matrix color by at least 5 units of hue if chroma and value are the same; at least 4 units of value or chroma if hue is the same; or at least 2 units of chroma or 3 units of value if the hue differs by 2.5 units. The last part of the definition differs from that of Day (1983) in order to avoid ambiguity between distinct and prominent.)

This summary of developments indicates two major steps in the classification of Gleysolic Soils. The first occurred in 1955 when the change was made from a field classification system (Stobbe 1945) to a "Taxonomic" system (Stobbe, 1955). The consequences of this change can be indicated by an example. Consider an area of undulating morainal soils in the Edmonton area of the Interior Plains. The field classification of an area, A, several kilometers square from the highest to lower levels would probably be: Grassland soil region, Black Earth soil zone, Deep Black Earth sub-zone, E association (depending on parent material), x, y, z etc. associates (the number would depend on local differences in drainage, salinity, etc.). Thus, to the fourth level, area A was a single entity in the field classification system just as it might be a single delineation of a map unit in today's terms. In the 1955 System, area A would almost certainly include soils of two classes at the highest level, Chernozemic and Gleisolic, and it might also include some Halomorphic and some Organic pedons. Area A might be designated using the 1955 system, as a delineation of map unit E including dominantly Black soils developed in weakly-calcareous till of clay loam texture, with Meadow and Podzolic Glei soils occupying the depressions, approximately 20% of the area, and minor inclusions of Black Solonetz soils.

The 1945 system was a system for classifying map units; the 1955 system was designed to classify soil individuals within map units. Thus, as shown in the example, a logically established map unit might include several classes of soil even at the highest categorical level. Though this consequence was understood by Stobbe (1945, 1955) and though it imposes no constraint on the way soils are mapped, it is viewed as a problem by some pedologists to this day.

The second major change occurred in 1963 when relatively precise criteria were introduced for Gleysolic soils (Ehrlich, 1963). This was done, in part, because of the lack of uniformity in soil classification based on general definitions of classes. The recently published criteria developed in the United States (Soil Survey Staff, 1960) served as a ready-made recipe to try. Application of those and somewhat modified criteria that followed resulted in assignment of pedons to classes that were at odds with local concepts of how the soils should be classified. Some ignored the criteria and others applied them and suggested the changes that have been discussed at numerous national soil survey meetings.

The developments in classification and concepts of Gleysolic soils in Canada have evolved as a result of both developments in other countries and research in Canada.

RESEARCH RELATED TO GLEYSOLIC SOILS

The vast literature on gley phenomena and processes in soils is not reviewed fully; rather, we attempt to summarize some major findings and their consequences on soil classification in other countries, and to provide more complete coverage of research in Canada.

Developments in Other Countries Prior to 1960

The phenomenon of gleying and its association with waterlogging, lack of oxygen, reduction of iron, drab gray, greenish or bluish gray colors has been known in soil science from the early years of this century (Joffe, 1936; Bloomfield, 1949) if not before. In many countries of western Europe, surface water gley (pseudogley) and groundwater gley soils have been considered as different classes at the highest level for more than thirty years (Muckenhausen, 1963, see also papers in Pseudogley and Gley, E. Schlichting and U. Schwertmann, eds. 1973). In North America, this distinction was not made. It was understood from work such as Bloomfield's (1951) that in saturated soils with available energy sources, respiration of heterotrophic bacteria resulted in depletion of oxygen, reducing conditions and transformation of Mn(IV) and Fe (III) to reduced, more soluble forms. Removal of ferric oxide coatings resulted in the drab gray color of some gley soils; others were greenish-or bluish-gray due to formation of colored ferrous compounds. Localized oxidation of Fe(II) and Mn (II) and deposition of the oxides resulted in brown to black mottling.

The United States System, 1960

Soils with properties reflecting a major influence of periodic saturation

and reduction were classified in the 7th approximation as Aqu suborders of seven of the ten orders, replacing the former Humic Gley, Low Humic Gley and Half-Bog great groups (Soil Survey Staff, 1960). These great groups had been in the Hydromorphic suborder of Intrazonal soils (Thorp and Smith, 1949). The relatively precise criteria stated for the new Aqu suborder had common elements but they differed in detail from order to order. For example, low chromas, depending on hue, accompanied by prominent mottling at some specified depth were diagnostic of all Aqu suborders, with the exception of an Ae horizon of Mollisols. A histic epipedon alone, however, was diagnostic of Aquents, Aquepts, Aquolls and Aquods, but not of Aqualfs and Aquults. The criteria were based upon generalization of properties of pedons that had been described, and on limited testing of the resulting classification of other pedons in relation to the apparently appropriate classification. In Canada, we adopted only the color and depth criteria specified for Aquents and Aquepts as diagnostic of Gleysolic soils (Canada Department of Agriculture, 1970).

Research in Canada to 1960

Nearly all of the information about soils that would now be classified as Gleysolic came from soil survey work. Such soils were described in reports from all provinces and analytical data were given for some of them. During the last decade of the period matrix colors were indicated by Munsell units in some reports but mottles were described only in general terms, such as rusty mottles. The paucity of specific research on processes and properties of Gleysolic soils is evident from Atkinson's (1971) bibliography, where there are no entries under gley or Gleysolic prior to 1960.

Ignatieff's (1937, 1941) work on ferrous iron in soils was probably the first published Canadian research related to processes involved in Gleysolic soils. He found that aqueous $AlCl_3$ (3% solution) was an effective extractant of Fe(II) in soils and his results indicated that it did not reduce Fe(III). Waterlogging of soils resulted in marked increases of extractable Fe(II). Only minor amounts of Fe(II), however, were in solution in waterlogged columns of soil. Thus, much of the reduced iron must have been absorbed as exchangeable Fe(II). Ignatieff (1941) showed that his field test for Fe(II) involving extraction of soil with $AlCl_3$ and color development with dipryridyl yielded only traces of Fe(II) in well-drained soils, and appreciable amounts in waterlogged soils. After aeration of waterlogged samples, extractable Fe(II) decreased markedly thus indicating rapid oxidation. Sterilized waterlogged samples yielded only minor amounts of Fe(II) relative to unsterilized, waterlogged samples of the same soil. This indicated that reduction of iron is largely a biological process.

To our knowledge, this work had little influence either at the time of publication or decades later when bases of specific criteria for Gleysolic soils and useful field tests were sought. No record is available of thorough checking of the usefulness of the field test proposed, though use of $AlCl_3$ as extractant was questioned by Bloomfield (1951). Recently, Childs (1981) recommended a similar procedure for use in New Zealand.

McKeague (1958) studied the properties and genesis of "slough podzols" or "bluff podzols", gleyed soils with eluvial horizons in depressions in the

subhumid prairie region. They differed from the associated Chernozemic and Gray Wooded soils in their drab colors and mottling, and probably in their redox potentials as indicated by studies of soil columns in the laboratory. He concluded that many such soils should be classified in the existing system (Stobbe, 1955) as Gray Wooded Glei but that Eluviated Glei would be a better name. Some of the soils, however, were thought to belong with the imperfectly drained Gray Wooded class.

McKeague and Bentley (1960) reported that redox potentials of soil in columns with ground aspen leaves at the surface responded to fluctuations in water table. Potentials of -150 to -200 mv were measured in the permanently saturated column and Fe(II) was present in the leachate. Potentials in freely drained columns were +600 to +700 mv. With no organic matter added, redox potentials did not decrease on waterlogging.

Research in Europe since 1960

Papers in Gley and Pseudogley (Schlichting and Schwertmann, eds., 1973) reflect the state-of-the-art on gleyed soils particularly in Europe, in 1970. In most European countries, groundwater gley and pseudogley soils were, and still are, distinguished at a high level in classification systems. Basic supporting data on water regimes, soil morphology and redox conditions at different depths, however, are not convincing. Some of the data for surface water gley soils can be interpreted as indicating high groundwater tables (Thomasson, 1973). Many soils probably are influenced both by groundwater and temporarily perched surface water. The split betwen pseudogley and groundwater gley soils is based more on concepts of genesis than on either clearly documented evidence of different water regimes or distinctive soil properties that indicate the cause of gleying (Muckenhausen, 1965). Some of the concepts involved and a number of the gley types included in the French system are given by Duchaufour (1982).

Papers at the Gley and Pseudogley conference (E. Schlichting and U. Schwertmann, eds., 1973) and discussions during the associated field trips indicated the prevailing concepts of relationships between soil morphology and kind of gleying. An interpretation of those concepts follows. Soils having high groundwater tables should have a gray unmottled horizon below the general maximum depth of the water table. Above this horizon in the zone that is saturated periodically, the soil should be gray with reddish brown to black nodules or coatings of iron oxide or of iron and manganese oxides. These oxides should tend to occur at the surfaces of peds because Fe(II) and Mn(II) within the waterlogged soil should diffuse to the drying surfaces of peds when the water table falls. Hence oxidation and deposition should occur at or near the ped surface. In some cases, Fe and Mn oxides may be deposited in a horizon above a relatively stable water table. In pseudogley soils, on the other hand, reduction is considered to be most intense at the surfaces of peds in the soil above the relatively impermeable horizon. It is plausible that water carrying some organic material fills the large interped pores after heavy rains, microbial activity depletes the oxygen, reducing conditions develop and Fe(III) is reduced near the surface of peds. Some of the Fe(II) formed migrates with the soil solution toward the unsaturated interior of the ped where it may be reoxidized. Thus pseudogley soils tend to have bleached

ped faces and Fe rich nodules or other deposits within the peds above the relatively impermeable layer.

Testing of these concepts in relation to the morphology of soils designated as groundwater gley or as pseudogley showed that they were not adequately valid. Some soils had both bleached ped faces and reddish brown, presumably iron-enriched ped faces. There seemed to be no consistent difference in gley morphology of soils designated groundwater gley and pseudogley.

The same problem between concepts and morphology of presumed groundwater and surface water gley soils was evident on the excursion in England that followed the 1981 micromorphology meeting (Murphy and Bullock, eds. 1981). Mr. Avery, author of the British classification system (Avery, 1980), expressed doubts about the desirability of the separation of surface and ground water gley soils at the major group level. The separation in the British system is based mainly upon whether or not there is a slowly permeable (Ksat horizontal 10 cm day^{-1}) subsurface horizon.

Ponnamperuma (1972) summarized the chemistry of submerged soil including many of the basic data required for calculating equilibria in soil systems under various oxidation reduction conditions. He showed that the sequence of reduction in soil systems is as follows: oxygen, nitrate, manganese, iron, sulfate. Despite the theoretical and practical problems involved in obtaining reliable redox potential measurements in soil, he reinforces the view that measurement of the redox potential of a soil provides a quick, useful, approximate measure of its oxidation-reduction status.

Brinkman (1970) introduced the concept of "Ferrolysis" to explain the low pH of some gley horizons near the soil surface. This proposed mechanism is summarized following Bouma's (1983) explanation. When a soil is reduced, ferrous iron replaces some of the exchangeable bases and Al. The displaced cations may be leached laterally and downward from the horizon. Upon aeration and oxidation, exchangeable Fe(II) would be oxidized producing ferric hydroxide and hydrogen ions; $Fe(II)+3H_2O = Fe(OH)_3+3H^+$. The hydrogen ions would attack silicate minerals if carbonates were absent, releasing Al which would dominate the exchange complex and perhaps form interlayers in clays.

The mechanism is plausible under certain conditions: absence of carbonates, effective removal of solutes, negligible upward movement of basic cations from below the water table. It is probably a minor process in most Gleysolic soils in Canada as Aeg horizons of Gleysolic soils do not typically have lower pH values than corresponding horizons of the associated soils.

Siuta (1967) summarized some of the eastern European views on gley phenomena in relation to water regimes. In his view, gley phenomena can be used effectively to assess water regimes and oxidation reduction conditions of soils if differences associated with texture are taken into account.

Zaydel'man (1984) concluded, however, that soil classification based on morphological characteristics associated with hydromorphism are inadequate.

He suggested development of a system based upon ecological-hydrological principles but specific definitions of classes were not given.

Murphy (1984) reported detailed information including micromorphological features of surface water gley soils in England. Many of the gleyed horizons had neoalbans (bleached ped surfaces) but some also had neoferrans or neomangans (surfaces stained with iron or manganese enriched material). The micromorphological features, though interesting, do not appear to be a useful basis for differentiating Gleysolic soils.

Research in the United States since 1960

Some results of research in the United States are reflected in the criteria of Aqu suborders in Soil Taxonomy (Soil Survey Staff, 1975) as compared with those in the 7th Approximation (Soil Survey Staff, 1960). For example, in the case of Aquents specific color criteria are given in Soil Taxonomy for soils that are permanently saturated with water as opposed to those that are saturated periodically. In addition, color criteria depend, to some degree, on texture. For Aquolls, the diagnostic color criteria apply to the material, "immediately below the mollic epipedon, or within 75 cm of the surface if a calcic horizon intervenes", (Soil Survey Staff, 1975). Also, a calcic or petrocalcic horizon that has its upper boundary within 40 cm of the surface is diagnostic of Aquolls for Mollisols that do not have an albic horizon, and that either have an aquic moisture regime or are artificially drained. Similarly, the diagnostic criteria of other Aqu suborders were modified on the basis of information obtained between 1960 and approximately 1970.

Some of the more recent findings on relationships between soil water regime and gley morphology in soils of Wisconsin were summarized by Bouma (1983). He showed diagrammatically some relationships between pressure potential of soil water, redox potential and gley phenomena. For example, according to the diagram, matrix chromas below 2 are most common in water saturated horizons having redox potentials such that Fe and Mn are in reduced states throughout the year. Manganese coatings and nodules are indicated as being most common in horizons that are saturated for only brief periods and that have redox potentials such that Mn is reduced for brief periods while Fe remains oxidized. Similar relationships between water regime and gley morphology were reported by Anderson (1984) for soils of Minnesota. Franzmeier et al. (1983), however, found that some Indiana soils that were saturated for prolonged periods had matrix chromas of 3. Vepraskas and Wilding (1983) reported on soils in Texas having aquic moisture regimes and matrix chromas of 3. They suggested that albic neoskeletons (bleached ped surfaces partly depleted of clay) are diagnostic of aquic regimes.

Several other recent publications report on specific relationships between gley morphology and either soil drainage class or measured water table fluctuations. Richardson and Hole (1979) noted gray mottles in moderately well and somewhat poorly drained soils; ped surfaces in the latter were of lower chromas. Poorly drained soils in the Glossoboralf Haplaquoll sequence in northwestern Wisconsin had gray albans (bleached ped surfaces) and Fe Mn nodules. The very poorly drained soils had thick albans underlain by

quasiferrans (iron enriched subsurface deposits) and gley colors. Zobeck and Ritchie (1984) concluded that for the soils they studied in Ohio, low chroma mottles implied a greater degree of saturation with water than ped coatings of the same color value and chroma (4/2).

Pickering and Veneman (1984) and Veneman and Bodine (1982) described colors and mottling in detail in coarse to medium textured soils with fragipans in Massachusetts. They found that terminology used in micromorphology (Brewer, 1964) was helpful in describing mottling patterns and that morphology indicated water regimes and oxidation reduction conditions.

Overall, considerable research has been reported in the United States recently showing relationships between measured or inferred soil water regimes and gley phenomena such as low chromas and mottles of high and low chromas. The tacit assumption is made in some of this work that the present water regime is the same as that prevailing during soil genesis. In general, the results suggest that observable gley phenomena depend not only upon current and previous water regimes and redox conditions but also upon the nature of soil material and perhaps on other factors. The present morphological criteria (Soil Survey Staff, 1975) diagnostic of Aqu suborders are not adequate in indicating aquic moisture regimes in some soils.

Research in Canada 1960-1981

Research related to Gleysolic soils was probably motivated mainly by two developments since 1960:

1. Increased focus on soil water regimes by the CSSC. Matthews (1963) defined soil moisture classes in terms of duration of water content in excess of field capacity; formerly these classes were based on morphology (color and mottles). The focus on wetness per se encouraged work on direct measurement of soil water. McKeague (1970) recommended the development of a system for classifying the various aspects of the soil water regime such as water table, water content and infiltration. The need for long term data at well-chosen sites was stressed and sources of some of the available data on water tables, hydraulic conductivity etc, were summarized. Discussion of soil water regime characterization continued under the chairmanship of Mackintosh (1973, 1976) and a new system was recommended for trial in 1981 (Nowland, 1981). The system classifies several attributes of the soil water regime: aridity index, soil transmissibility, saturated zone, seepage, year-round water state. This specific framework will undoubtedly lead to increased data collection and testing of the system.

2. The advent of specific criteria in soil classification in Canada after 1963 (Ehrlich, 1963). Pedologists were encouraged to test the low chroma and mottling criteria on the soils being mapped. Problems were identified and some of them became the topics of research.

Some specific examples of research related to Gleysolic soil classification are outlined; undoubtedly some of the relevant publications will be missed.

A. Field studies relating soil water table to soil color, mottling, redox potentials, etc.

McKeague (1965 a and b). Data on water tables and redox potentials were reported for a two year period at 3 uncultivated sandy soil sites and 3 uncultivated clayey soil sites of differing degrees of wetness near Ottawa and soil samples were analyzed. In general, redox potentials reflected the water table; potentials below 100 mv occurred only in saturated soils. Low chromas and prominent rusty mottles occurred only in horizons subject to periodic saturation. In the poorly drained sandy soil, there was a marked accumulation of dithionite-extractable Fe above the summer water table level. This and like soils were the basis of the Fera subgroups of Gleysolic soils first defined in 1965 (Ehrlich, 1965). In general, the results of this study were consistent with the conceptual model of relationships among water table, redox potentials and soil morphology.

Crown and Hoffman (1970) undertook to determine whether kinds of mottles could be related to the depth to water table. They described four profiles on a 2% slope, measured the water table regularly from May to the end of August and noted that the water table was at the surface at all sites in October. A trend was reported for more diffuse mottle boundaries and increase in mottle size and abundance with increased duration of saturation of the horizon.

Macyk et al. (1978) measured water table, water content, temperature and redox potential at seven sites on a till knob near Edmonton from May through October for a 2-year period. Soils were described and samples were analyzed. They reported relationships among water table, redox potential and soil morphology.

DeKimpe et al. (1974) studied soil morphology, water table and redox potential at 5 sites on a slope near Quebec City. The general findings were similar to those of McKeague (1965 a and b) though they reported reducing conditions and gley mottles in a horizon that was saturated periodically but was never below the water table as measured in a well with a perforated lining.

Michalyna (1974) and Michalyna and Rust (1984 a and b) reported on studies of clayey and sandy soils in southern Manitoba. They measured water table, redox potential, temperature and groundwater composition in some of them. Some of the soils classified as Gleysolic (Michalyna, 1974) had water tables that remained below 1 m and high redox potentials throughout the period of measurement. In some, water was ponded at the surface in the spring over frozen subsoil and low redox potentials were measured near the surface.

All of the soils had matrix colors of relatively low chroma (usually 1 or 2) and most of them had distinct to prominent mottles at some depth. Current criteria were not adequate to distinguish some of the pedons that were classified on the basis of early concepts as Humic Gleysols from some of those classified as Black (Chernozemic). Several of the sandy soils had light gray, carbonated subsurface horizons.

Most of these few studies and similar studies done in other countries show

a good general relationship among water table, redox potential and morphological indicators of oxidation-reduction but there are exceptions. Few of the studies report morphology in adequate detail to aid in evaluating the specifics of morphological criteria of gleying and in some of the publications there is little relationship between the reported Munsell colors of matrix and mottles, and the adjective used to describe prominence of the mottles.

B. Other Studies Involving Analysis of Samples of Gleysolic Soils.

Michalyna (1971) reported detailed morphological and laboratory measured properties of eluvial soils in Manitoba ranging from Orthic Gray Luvisol to Humic Eluviated Gleysol. In his view the color and mottling criteria were not entirely adequate for distinguishing Eluviated Gleysols from Gleyed Gray Luvisols. Extractable Fe and total Mn data were useful in distinguishing the soils studied. For example, total Mn maxima occurred at progressively lower depths in progressively more strongly gleyed soils. Also, ratios of oxalate to dithionite extractable Fe in BC horizons were progressively higher for progressively more strongly gleyed soils.

McKeague et al. (1971) analyzed five gleyed soils having B horizons with prominent rusty mottles, possible Fera Gleysols. All of the soils whether acid or neutral had maxima of dithionite-Fe in a prominently mottled B horizon but only two of them met the requirement for a Fera subgroup (Bgf horizon, at least 1% more dithionite-Fe than the associated C horizon). Geothite was detected in most of the rusty mottles analyzed.

Michalyna (1974) and Michalyna and Rust (1984 a and b) found that distribution with depth of Fe and Mn and the ratios of oxalate to dithionite Fe in soils of the Red River-Osborne and the Almasippi associations did not follow the trends noted in a previous study of Gleyed Gray Luvisols and Luvic Gleysols (Michalyna, 1971). Soils of the sandy Almasippi association had low levels (0.1-0.2%) of dithionite-Fe (Fe_d) in the A horizon. There were no maxima of Fe_d in mottled horizons.

Stonehouse and St. Arnaud (1971) showed that Gleysolic soils differed from Chernozemic, Solonetzic and Luvisolic soils of Saskatchewan in having a high ratio of oxalate to dithionite extractable Fe (Fe_o/Fe_d) in the Ae horizon. They suggested that Gleysolic soils might be separated from others on the basis of an Fe_o/Fe_d ratio 0.35 in the upper horizons.

C. Other Related Research

Eilers (1973) completed an important study in which he related groundwater flow to soil morphology in southwestern Manitoba. He showed definite relationships between groundwater flow and soil properties. For example, eluviated soils were associated with groundwater recharge areas whereas saline and carbonated soils occurred in discharge areas. The work shows the importance of considering point information on water tables and soil morphology in the context of information on groundwater flow systems of the area generally. Similar studies have been done recently in Saskatchewan (Miller, 1983).

Mackintosh and Van der Hulst (1978) measured water tables of well, imperfectly, poorly and very poorly drained soils of five catenas in Ontario. The drainage classes were assigned according to soil morphology and landscape position. The authors calculated the number of days that a soil contained free water at various depths from 30 to 150 cm and related the duration of saturation at these depths to drainage classes. Though duration of saturation at a given depth was longer, in general, for increasingly poorly drained soils, there was much overlap between classes. Variation of duration of saturation within a drainage class was great. In terms of the Gleysolic order - Gleyed subgroups problem, the results could be interpreted as further evidence that soil "wetness" classes are not the same as "degree" of gleying classes.

McKeague (1965c) studied the effect of nature of soil material on evidence of gleying in samples subjected to controlled water table conditions in the laboratory. Gley phenomena (gray colors and rusty mottles) developed most clearly and rapidly in samples of brownish color that contained organic matter. Little change occurred in a sample of gleyed, gray clay regardless of treatment. Low redox potentials developed much more rapidly at room temperature (approx. 23°C) than at 5° or especially at 1°C. Potentials below 0 mv did develop, however, in some samples maintained at 1°C.

PROGRESS REPORT ON RECENT RESEARCH

Field Trip in Manitoba and Saskatchewan, June 8-12, 1981.

We looked at a variety of soils developed in water-deposited clays and sands, and in till; most were classified as either Gleysolic soils or Gleyed subgroups of Chernozmic soils. The trip was a good example of the fact that there is no substitute for seeing the soils in the landscape with the people who map, correlate, and interpret them for various uses. Problems in soil classification have to do with personal and regional concepts, history, concerns about interpretations, and various other issues in addition to the complex problems of dividing the continuum of soil properties into unambiguous classes that make sense.

Some of the soil problems noted were:

1. Soils with a chernozemic A underlain by a horizon at a depth of approximately 25 cm enriched in secondary carbonates and gray (5Y 4/1). Below this horizon the calcareous material may or may not be mottled. Strict application of the current criteria (CSSC, 1978) would result in classification of such soils as Humic Gleysols. The carbonated horizon has a chroma of 1 or less. The low chroma may be due, however, to the color of the secondary carbonate and not to reduction. In Soil Taxonomy, such a soil would be an Aquoll because a calcic horizon within 40 cm is diagnostic if either an aquic moisture regime or artificial drainage are assumed. In the FAO legend (FAO-Unesco, 1974) it would be a Chernozem (not a Gleysol because the calcic horizon is not diagnostic of Gleysols). It might be desirable to exclude the color of a carbonated horizon as an indicator of gleying and to base the classification on properties of the

horizons above and below. On the other hand, perhaps the presence of a carbonated horizon near the surface indicates that the soils were formed under high water table conditions (presumably reducing) and that cultivation, roads, etc have resulted in lower water tables.

2. Prominently mottled sandy soils on slopes (Long Plain site). Though the mottles below the Ah were prominent, the matrix chromas were 2 to 3. Insisting on matrix chroma of 2 or less accompanied by prominent mottles would exclude the soil from the Gleysolic order, but problems might arise elsewhere.

3. Clayey soils with chromas of 1-2 and some barely-visible rusty mottles below the black Ap (Red River-Osborne soils). Present water tables in these soils are not close to the surface but they might have been subject to annual flooding before the area was settled.

4. Rusty mottles indicative of gleying in soils that appear otherwise to be "well drained". A soil on the upper slope in a hummocky till area near Carlyle, Sask. had distinct brown mottles in the Bm horizon (10-18 cm), and there were some prominent mottles in the underlying horizon. It is possible that the soil was gleyed due to saturation of the upper material above frozen subsoil in the spring (Michalyna, 1974). Gley phenomena are very common in horizons overlying permafrost in Cryosolic soils (Zoltai and Tarnocai, 1974).

In addition to soil problems there were problems associated with different concepts. Some of these are:

1. Some pedologists equate Gleyed subgroups with imperfect drainage and Gleysolic soils with poor or very poor drainage. Others consider the drainage classes as indicators of relative wetness; Gleysolic soils are based on evidence of periodic or prolonged reduction during their genesis. Thus, an area that was flooded every spring before road ditches provided drainage might now be saturated only rarely. Soils of the area might be Gleysolic (evidence of reduction) but moderately well drained now though they were formerly poorly drained.

2. To a degree, each observer sizes up the nature of the soil and site, decides how the soil should be classified, and then focuses on the soil properties that support the decision, while paying scant attention to properties that do not fit. Of course, it is essential to describe soil properties objectively, but few succeed entirely. Thus, some could see mottles and others could not; some read chromas of 3 and others noted chromas of 1 or 2.

3. There is a strong tendency for individuals working in a particular area to use the whole range of soil classes available to flag differences in degree of gleying or other features. Thus, at the subgroup level, there are only three classes of gleying to apply to all of the soils of Canada: Orthic subgroups, Gleyed subgroups, and Gleysolic soils. In a local area, though there may be differences in degrees of gleying, all of the soils may fit into one or two of these classes. The differences can be

indicated as phases of subgroups or at the series level.

4. Some of the differences in concepts are due to ambiguities in the classification system (CSSC, 1978) as mentioned previously.

5. Some pedologists feel that the earliest concept of genesis and classification of the soils of an area was "right" and that refinements based on additional data, increased knowledge and further pondering should not alter the initial classification.

Visits to soil-hydrology sites near Deloraine and Hamiota were very convincing in showing the usefulness of having a feel for and data on groundwater flow in the area where soils are being studied (Eilers, 1973).

Soil Classification-Correlation Tour, B.C., Aug. 19-21, 1981.

Problems in classification of Gleysolic soils and gleyed subgroups were among those considered by Tarnocai with B.C. pedologists. After observing soils in the Lower Fraser Valley, Vancouver Island and Saltspring Island and discussing criteria the group reached the following conclusion:

Two basically different conditions occur in wet soils:

(a) reduced conditions indicated by matrix colors of low chroma (gray and greenish-gray) which are usually associated with stagnant water; and (b) mottled conditions which result from alternating reducing and oxidizing conditions and are associated with a fluctuating water table, periodic perched water table or prolonged saturation during long periods of high rainfall.

The following criteria were tested during the tour and found to be workable for Gleysolic soils and gleyed subgroups of other orders. These criteria have already been used, to a limited extent, for classifying these soils in the Langley-Vancouver Soil Map Area.

Gleysolic - Gleysolic soils have features indicative of prolonged saturation with water which results in the development of reducing conditions. These soils have matrix colors of low chroma (colors usually fall on the 5Y and Gley color charts) within 50 cm of the mineral surface. The horizons of these soils are designated with the suffix "g" (e.g. Bg, Cg).

Gleyed Subgroups - The gleyed subgroups of other orders have features indicating fluctuating water table or reducing conditions below the 50 cm depth. The fluctuating water table results primarily in the development of mottles. The horizons associated with these mottles are indicated by adding the suffix "gj". Following examination of soils during the tour, the following criteria were developed:
Gleyed subgroups have distinct or prominent mottles above the 50 cm depth but do not display reduced (gray) colors. The mottled layer must be greater than 10 cm thick and the upper half of this layer must be above the 50 cm depth. If

> mottling occurs in alternate layers, the total thickness must be greater than 10 cm and at least half of this should occur above the 50 cm depth. These soils may or may not have reduced horizons within the control section. If reduced horizons occur, these must be below the 50 cm depth.

Some participants indicated that problems arose when these criteria were applied to those soils with inherent dark parent material (e.g. material derived from shales) and to soils with large amounts of free carbonates present. Since the reduced colors and mottles are difficult to observe in these soils, it was suggested that, for these soils, additional information (such as the presence of a peaty surface horizon, depressional landscape position, vegetation, and occurrence of long-term ponding) should be used. In some climatic regions a peaty surface layer indicates saturation.

Conclusions of the B.C. group are compatible, in part, with suggestions emanating from the Manitoba-Saskatchewan field trip. For example, insisting on low matrix chromas (how low must be decided) within 50 cm of the surface for Gleysolic soils was mentioned by both groups. The criteria proposed by the B.C. group (if reduced colors imply chromas of 1 or less), however, would result in shifting the Gleysolic order - gleyed subgroup boundary far toward the Gleysolic side; they would result in reclassification as gleyed subgroups of many soils currently designated as Gleysolic; for example, soils having above 50 cm horizons that are prominently mottled with matrix chroma of 2.

Carbonated Samples

Samples of a few carbonated horizons sent by Michalyna were flooded with water for several months and Ept was read periodically. Ept readings did not fall below 350-400 mv and no ferrous iron was detected in the water. Addition of half a gram of sucrose to some of the samples brought about a rapid drop of Ept to -300 mv, and a ferrous iron was readily detectable in solution. Reduced carbonated samples became distinctly more greenish in color (5GY) though they were gray (5Y 6/1) initially. These samples had very low dithionite extractable Fe contents (0.1% or less) and most of them contained less than 0.5% organic carbon. Subjecting them to several oxidation reduction cycles did not result in the formation of distinct rusty mottles.

These preliminary results are consistent generally with those of Michalyna (1974) working with similar soils. He found that low Ept values did not occur in columns of Almassippi soils unless the Ap was saturated. Apparently, the subsurface soil does not provide an adequate energy source to promote microbial growth and thus deplete oxygen. Ah horizon material or sucrose provides the required energy source. McKeague (1965c) on the other hand measured low Ept values in some flooded B and C horizon samples maintained at room temperature. In this case, the tubes containing the samples were stoppered; thus there would be little diffusion of oxygen into the samples.

B.C. Samples

Five pedons of Gleysolic soils or Gleyed subgroups, some of which were

difficult to classify, were described and sampled by the B.C. soil survey. The samples were analyzed in the Kelowna laboratory and thin sections were prepared described and analyzed in Ottawa. Improved criteria were sought for setting the limit between Gleysolic soils and Gleyed subgroups. An analysis of the results shows that four of the five pedons were classified appropriately in the view of B.C. pedologists if the specific color criteria given on page 69 of the Canadian system (CSSC, 1978) were applied (McKeague et al. 1985). The other pedon, classified as Bates series, definitely met the color criteria specified for the Gleysolic order though the water table now is rarely within 1 m of the surface. Prior to drainage, however, the water table was probably at or near the surface for prolonged periods. Thus the pedon is appropriately classified as Gleysolic because during most of its period of genesis it was presumably subjected to reducing conditions during part of each year. Drainage has resulted in lowering the water table and the soil is no longer poorly drained. Chemical and micromorphological data did not provide an improved basis for differentiating Gleysolic soils from gleyed subgroups of other orders (McKeague et al. 1985).

PROPOSALS DEVELOPED IN 1984

Based on observations and discussions during field trips, notes from correlators and correspondence from pedologists in several regions, we proposed changes in criteria of Gleysolic soils for testing in all regions. The proposals, the results of testing them in several regions and the changes agreed upon at the meeting of the Expert Committee on Soil Survey (ECSS) in Guelph, Nov. 1984 are given in detail in the proceedings (Shields and Kroetsch eds. 1985). The major changes and some related concepts are summarized here.

Concepts Involved

1. Criteria for the Gleysolic order or any other class at the order level, should be compatible with the concept of the order. In the Canadian system (CSSC, 1978), "Taxa at the order level are based on properties of the pedon that reflect the nature of the soil environment and the effects of the dominant soil forming process". In the case of Gleysolic soils, the nature of the soil environment throughout much of the period of genesis is saturated with water and under reducing conditions for appreciable periods most years. The dominant soil forming process is gleysation due to reduction or intermittent reduction and oxidation within 50 cm of the surface, and the properties known to reflect this are gley colors with or without mottles.

Gleysolic soils are those in which the imprint of reduction or reduction-oxidation cycles is dominant over evidence of persistent oxidizing conditions. Many Gleysolic soils are poorly or very poorly drained, some are imperfectly drained, and others, in which drainage has been markedly improved, are now well drained. Criteria for Gleysolic soil classification must be based on soil properties that indicate reduction during the genesis of the soil, not on the current soil water regime. A major step toward improved classification of Gleysolic soils would be acceptance of the concept that there is not a 100% correlation between drainage class or current soil water

regime and soil taxonomy.

Consider the clayey soils on level terrain in parts of the St. Lawrence Lowlands of southern Ontario and Quebec. Large areas of such soils were undoubtedly subject to reducing conditions in their natural state and many still display the evidence of such conditions - low chromas accompanied by prominent mottles near the surface. Some of these soils were drained and cultivated more than a century ago, others more recently. Suppose that an effectively drained field of such a soil has not been saturated to the surface for more than a few hours in the last 50 years and that reducing conditions have not occurred in the upper meter during that time. The soil might be designated as imperfectly drained, perhaps even moderately well drained. Prominent mottles persist, however, immediately below the Ap horizon. Matrix chromas are 2 in the upper B and perhaps 1 to 2 in a depth of 1 m.

Considering the fact that our system is based upon properties that reflect genesis, is it not preferable to classify such soils as Gleysolic (perhaps Humic Gleysols) that are imperfectly or well drained (or preferably give the appropriate SWIG classes) than to insist that the drainage class and the taxonomy are "compatible" and classify them as gleyed subgroups of other orders, perhaps Gleyed Melanic Brunisol? Many soils of the St. Lawrence Lowlands were probably periodically flooded and reduced for thousands of years and they still bear the marks of their genetic history. In time, if the drains continue to function, such soils may lose their gley features and be appropriately classified in another order. In the meantime, much information about the soil is implied in the designation, Humic Gleysol, imperfectly drained.

2. In cases where two or more apparently "dominant soil forming processes" have left their mark on the soil, it is essential to decide an order of precedence. The decision on this is reflected in the present "Key to soil orders" (Canada Soil Survey Committee, 1978). No change is proposed in the order implied previously. Hence, processes reflected by permafrost close to the surface, by the accumulation of organic material of specified thickness, and by podzolic processes giving rise to soils that meet the specifications of the Podzolic order take precedence over evidence of gleysolic processes. Specified evidence of gleysolic processes, on the other hand, take precedence over processes leading to the development of a solonetzic B, chernozemic A, Bt, Bm, or to weak evidence of soil genesis as in Regosolic soils.

3. Classification criteria are based on observable or measurable soil properties, not on vegetation, slope position or other non-soil properties that are commonly related to soil properties (CSSC, 1978). Relationships between these associated properties and degree of expression of gley features facilitate mapping. They differ from region to region and in different soil materials. Elucidation of relationships between observable non-soil properties and key soil properties in an area is work of major importance. Pedons must be classified, however, on the basis of their properties rather than on the basis of inferred properties or genesis deduced from observation of such features as position in the landscape and vegetation.

4. Criteria for the Gleysolic order, or other order, should make sense from both practical and genetic points of view for soils of different horizon sequences, different parent materials, different climatic regions, etc. If they do not make sense in the collective view of Canadian pedologists, improved criteria should be sought, tested and put in place if suitable. Until such criteria are developed, pedons are classified according to the currently-accepted criteria, not on the basis of landscape features, vegetation, gut feelings, or local biases. If the criteria result in apparently illogical classification of pedons, the facts are recorded and used in developing improved limits or improved criteria for testing.

Accepted Proposals for Change

These proposals including ideas of pedologists from several provinces are aimed at fine-tuning of the present system. We did not develop new bases for criteria to separate Gleysolic soils from gleyed subgroups. In spite of the problems associated with its use, color is the best known simple indicator of long-term reduction-oxidation status of soil. Measurement of redox potential and use of dyes that react with Fe^{+2} (Childs, 1981) are useful for some purposes but they do not indicate prevailing oxidation-reduction status during soil genesis.

1. The Gleyed Gray Luvisol - Luvic Gleysol split.

   Currently, a soil having a Bt horizon, and low chromas accompanied by prominent mottling (see p. 69, CSSC, 1978 for details of colors) within 50 cm of the surface is a Luvic Gleysol. But some soils with unmottled, brown (chromas of 3 or 4) Bt horizons have Aeg horizons with chromas of 1 and prominent reddish brown mottles. By the book, these soils are Luvic Gleysols but they probably should be Gleyed Gray Luvisols (oxidiation dominant). The change required results in criteria for Luvic Gleysols similar to those for Aqualfs (Soil Survey Staff, 1975). Details of the changes are spelled out for testing later in this report.

2. Details of color criteria

   As pointed out previously, the Canadian system (CSSC, 1978) is ambiguous on the color criteria for Gleysolic soils. The change required is to specify either very low chromas or relatively low chromas, depending on hue, accompanied by prominent mottling within 50 cm of the mineral surface. The specific color criteria except for soils developed in red materials are:

   > chromas of 1 or less without mottles or hues bluer than 10Y, <u>or</u> chromas of 2 or less in hues of 10YR or redder and prominent mottles, <u>or</u> chromas of 3 or less in hues yellower than 10YR and prominent mottles. The prominent mottles to be diagnostic must occupy at least 2% of a horzon at least 10 cm thick with its upper boundary within 50 cm of the mineral surface.

3. Color criteria for soils developed in red materials

   Soils developed in some red materials (5YR or redder and color does not

fade rapidly on dithionite treatment) may not have subsoils of low chromas even if they are subjected to prolonged reducing conditions. In such soils, the following moist color criteria within 50 cm of the surface are diagnostic of Gleysolic soils:

a. Common or many, distinct or prominent mottles of high chroma in a horizon at least 10 cm thick with its upper boundary within 50 cm of the surface.

b. Common or many, prominent mottles of low chroma in a horizon within 50 cm of the surface.

Gray streaks associated with ochreous material along fissures in fragipans are not diagnostic of Gleysolic soils.

4. Add Solonetzic subgroups to the Gleysolic order

These would be parallel to the Luvisolic subgroups of Ferro-Humic and Humo-Ferric Podzols. They would identify soils that meet the criteria of Solonetzic soils except that they also meet the limits for Gleysolic soils. A decision would have to be made on the order of precedence of subgroups. Tentatively, we suggest that Solonetzic would take precedence over Rego, Fera and Luvic. Thus a Gleysolic soil having a Bng or Bntg horizon would be a Solonetzic subgroup of the appropriate great group.

5. Chromas of Ae and Ah horizons

Chromas of 1 occur in Ae and Ah horizons of some oxidized pedons classified as Chernozemic, Luvisolic, Podzolic, Solonetzic, etc. Strict application of the present criteria would result in misclassifying these pedons as Gleysolic. It is proposed that chromas of Ah and Ae horizons should not be diagnostic of Gleysolic soils. In the case of exceptionally thick Ah or Ae horizons, some adjustment might be required.

6. Low chroma mottles

Mottles with chromas of 2 or less are diagnostic of some Aquic subgroups in Soil Taxonomy. We have not paid much attention to mottles of low chromas except for reddish soils. It is proposed that common or many distinct or prominent mottles of low chromas in horizons of generally oxidized color within 1 m of the surface should be diagnostic of gleyed subgroups. An exception is made for reddish soils in which prominent low-chroma mottles at specified depths are diagnostic of Gleysolic soils.

7. Coastal Gleysolic Soils

Some Gleysolic soils in coastal sediments have black (N2/) horizons that turn gray (5Y 6/1) on oxidation. The need of a new class for these soils was mentioned. It is proposed that this feature should be recognized at the series level.

Other Proposals

Some of the proposals for changes in Gleysolic order criteria were either rejected or designated for further study. These are listed:

1. Soils with chernozemic A horizons and horizons of secondary carbonate enrichment, ca, within 50 cm of the mineral surface.

   Chromas of such ca horizons are commonly 1; thus, they meet the color criteria of Gleysolic soils unless an exception is made. The proposal to classify such soils as Humic Gleysols, consistent with some Aquolls in Soil Taxonomy (Soil Survey Staff, 1975), was set aside for further study especially in Manitoba.

2. The Humic Gleysol-Gleysol split

   Currently, the Ah of Ap horizon of a Humic Gleysol must: contain more than 2% organic C, have a rubbed color value of 3.5 or less (moist) or 5 or less (dry) and have a lower color value than the underlying horizon. This has caused problems. Some Ap horizons containing much more than 2% organic C have color values (moist) of more than 3.5. Also, some Ah or Ap horizons no darker than the underlying material contain substantially more than 2% organic C. The solution proposed is to restrict the diagnostic criterion for a Humic Gleysol to: Humic Gleysols have no Bt horizon; they have either an Ah horizon at least 10 cm thick or an Ap horizon at least 15 cm thick with more than 2% organic carbon. (The same A horizon criteria would apply to Humic Luvic Gleysols). Color and other morphological properties would be used to aid pedologists in making field estimates of organic C. The problem was recognized but agreement was not reached.

REVISED GLEYSOLIC ORDER CHAPTER

The statement of concepts and the minor changes in criteria outlined in the previous section of this report necessitate a redrafting of the Gleysolic order chapter of the Canadian system (CSSC, 1978). This section is a first draft of that revised chapter. It should be criticized in detail both for clarity and content and tested in classifying soils of all regions of Canada before further revision and eventually inclusion in a revised publication of the Canadian system. The draft that follows is intended to be complete except that photographs and diagrammatic sketches of Gleysolic soil profiles are not included.

GLEYSOLIC ORDER

Great Group	Subgroup
Luvic Gleysol	Solonetzic Luvic Gleysol SZ.LG
	Fragic Luvic Gleysol FR.LG
	Humic Luvic Gleysol HU.LG
	Fera Luvic Gleysol FE.LG
	Orthic Luvic Gleysol O.LG
Humic Gleysol	Solonetzic Humic Gleysol SZ.HG
	Fera Humic Gleysol FE.HG
	Orthic Humic Gleysol O.HG
	Rego Humic Gleysol R.HG
Gleysol	Solonetzic Gleysol SZ.G
	Fera Gleysol FE.G
	Orthic Gleysol O.G
	Rego Gleysol R.G

Note: The great groups and subgroups are arranged in the order in which they are keyed out. For example, if a Gleysolic soil has a Btg horizon, it is a Luvic Gleysol whether or not it has any of the following: Ah, Bn, Bgf, fragipan. The Luvic Gleysol is the first great group keyed out. Similarly at the subgroup level, if a Luvic Gleysol has a solonetzic B horizon, it is a Solonetzic Luvic Gleysol whether or not it has any of the following: fragipan, Ah, Bgf. In essence, any class at the great group or subgroup level as listed does not have the diagnostic properties of classes listed above it. For example, a Rego Gleysol does not have any of the following: a B horizon as defined for Orthic Gleysol, a Bgf horizon, a solonetzic B horizon.

Gleysolic soils are defined on the basis of colors and mottling considered to be indicative of the influence of periodic or sustained reducing conditions during their genesis. The criteria that follow apply to all horizons except Ah or Ap horizons and Ae horizons. If the Ae horizon is thicker than 20 cm and its lower boundary is more than 60 cm below the mineral soil surface, however, the criteria do apply to the Ae. Also if the Ah or Ap horizon is

thicker than 50 cm, the color criteria apply to the mineral horizon immediately below. Apart from these exceptions the criteria are as follows: Gleysolic soils have within 50 cm of the mineral surface the upper boundary of a horizon or subhorizon at least 10 cm thick that has moist colors as follows:

1. For all but red soil material (hue of 5YR or redder and color fades slowly on dithionite treatment).
   a. Dominant chromas of 1 or less or hues bluer than 10Y with or without mottles, or
   b. Dominant chromas of 2 or less in hues of 10YR and 7.5 YR accompanied by prominent mottles 1 mm or larger in cross section and occupying at least 2% of the exposed, unsmeared 10 cm layer, or
   c. Dominant chromas of 3 or less in hues yellower than 10 YR accompanied by prominent mottles 1 mm or larger in cross section and occupying at least 2% of the exposed, unsmeared 10 cm layer.

2. For red soil materials (hues of 5YR or redder and color fades slowly on dithionite treatment).
   a. Distinct or prominent mottles of high chroma at least 1 mm in diameter occupy at least 2% of the exposed unsmeared 10 cm layer, or
   b. Distinct or prominent mottles of low chroma at least 1 mm in diameter occupy at least 2% of the exposed unsmeared 10 cm layer.

Soils of the Gleysolic order have properties that indicate prolonged periods of intermittent or continuous saturation with water and reducing conditions during their genesis. Saturation with water may be due either to a high groundwater table, or to temporary accumulation of water above a relatively impermeable layer, or to both of these. Soils may be saturated periodically with aerated water or for prolonged cold periods that restrict biological acitvity without developing properties associated with reducing conditions. Such soils are not classified as Gleysolic.

Gleysolic soils are associated with a number of different water regimes which may change during the genesis of the soil. Commonly they have peraquic or aquic regimes but some have aqueous regimes and others are now rarely, if ever, saturated with water. The latter soils presumably had aquic regimes and were under reducing conditions in the past but drainage, isostatic uplift or other factors have resulted in changed water regimes.

Gleysolic soils occur in association with other soils in the landscape, in some cases as the dominant soils, in others as a minor component. In areas of subhumid climate Gleysolic soils occur commonly in shallow depressions and on level lowlands that are saturated with water every spring. In more humid areas they may occur also on slopes and on undulating terrain. Commonly, the native vegetation associated with Gleysolic soils differs from that of associated soils of other orders.

Some notes on the rationale behind the color criteria follow. The criteria are based upon color because color is the most easily observable and most useful indicator known of the oxidation-reduction status of a soil during its genesis. Color in itself is not considered to be important but it

indicates much about the prevailing processes involved in soil development in many materials. Redox potentials measured at several depths within pedons throughout the period when the soil is not frozen provide useful information on current redox conditions. Values of Ept of 100 mv or less are associated with reduced forms of Mn and Fe. Such values, however, indicate only present redox conditions not those that existed over long periods during which the soil developed. Similarly monitoring of water regime properties such as depth to water table provides valuable information on the present state of the soil, but it does not necessarily indicate the prevailing water regime during soil genesis.

Different color criteria are used for red soil materials than for others because it has been found that even prolonged saturation and, presumably, reducing conditions have not resulted in the development of drab gray colors in such materials. Usually, however, such soils are mottled in horizons near the surface. In some cases there are gray mottles in a reddish matrix, in others there are strong brown or yellowish red mottles in a matrix of lower chroma. The dominant color is considered to be the matrix color.

Exceptions had to be made in applying the criteria to soils with Ah, Ap or Ae horizons because chromas of 1 occur in some such horizons of oxidized soils. Furthermore, prominent mottling may occur in Ae horizons overlying relatively impermeable horizons of generally oxidized soils. In the case of thick Ae horizons, however, prominent mottling of the upper part of the horizon is thought to indicate periodic reducing conditions near the surface. These exceptions have not been tested and they will probably require adjustment.

The color criteria specify a minimum size and abundance of mottles in a subhorizon 10 cm thick or more because it seems unreasonable to base classification at the order level on the occurrence of minute or rare mottles in a thin layer. Care is required in estimating the abundance of mottles; smearing of ochreous material on the profile can result in overestimates and failure to look for both inped and exped mottles can result in underestimates. Use of mottle charts facilitates estimates of abundance. The minimum limits specified are an arbitrary cut through the continuum of degree of gley phenomena that exists in soils. Further information on soil properties in different regions will probably necessitate additional fine tuning.

In a particular region with a given soil material it will probably be possible to relate some combination of position in the landscape, vegetation, peaty surface or other easily observable features to the occurrence of the properties defined as diagnostic of Gleysolic soils. Such relationships will differ, however, from region to region. As stated by Ellis (1932) many years ago, in the final analysis, soil classification must be based on properties of the soil itself.

Distinguishing Gleysolic Soils from Soils of Other Orders

Guidelines for the distinction of Gleysolic soils from soils of other orders with which they might be confused are listed below.

Chernozemic. Some soils have a chernozemic A horizon and dull colors or mottling indicative of gleying within the control section. Those meeting the requirements specified for Gleysolic soils are classified in the Gleysolic order. Those having gley features within 50 cm that fail to meet the criteria of the Gleysolic order, or that have colors of low chromas, mottles, or both below a depth of 50 cm are classified as Gleyed subgroups of the appropriate great groups of Chernozemic soils.

Solonetzic. The soils with both a Bn or Bnt horizon and evidence of gleying as specified for Gleysolic soils are classified as Solonetzic subgroups of the appropriate great groups of the Gleysolic order.

Luvisolic. Some soils have eluvial horizons, Bt horizons and colors indicative of gleying within 50 cm of the mineral surface. Such soils are classified as Luvic Gleysols if gley colors as specified for the Gleysolic order occur in the Btg horizon within 50 cm of the mineral soil surface. If such gley colors occur either only in the Aeg horizon, with the exception for thick Ae horizons as specified, or only below a depth of 50 cm, the soil is classified as a Gleyed subgroup of the appropriate great group in the Luvisolic order.

Podzolic. Soils having both a podzolic B horizon and evidence of gleying that satisfies the specifications of Gleysolic soils are classified as Podzolic.

Brunisolic. Gleyed subgroups of Brunisolic soils are differentiated from Gleysolic soils on the basis of evidence of gleying too weakly expressed to meet the specifications of Gleysolic soils.

Regosolic. Soils with no horizon differentiation apart from evidence of gleying as specified for Gleysolic soils are classified as Gleysolic.

Organic. Gleysolic soils may have organic surface layers, but they are too thin to meet the minimum limits specified for soils of the Organic order.

Cryosolic. Some Cryosolic soils have matrix colors of low chroma and prominent mottling within 50 cm of the surface like Gleysolic soils. However, Gleysolic soils do not have permafrost within 1 m of the surface or 2 m if the soil is strongly cryoturbated.

Gleysolic soils are divided into three great groups: Luvic Gleysol, Humic Gleysol, and Gleysol, which are separated on the basis of the development of the Ah horizon and the presence or absence of a Bt horizon as shown.

Gleysolic Order

Luvic Gleysol	Humic Gleysol	Gleysol
A Btg horizon Usually an Ahe or an Aeg horizon	Ah, at least 10 cm thick No Bt horizon	No Ah or an Ah 10 cm thick No Bt horizon

LUVIC GLEYSOL

Soils of this great group have the general properties specified for the Gleysolic order and a horizon of clay accumulation. They are similar to Luvisolic soils except that they have dull colors or prominent mottling or both, which are indicative of strong gleying. They may have organic surface horizons and an Ah horizon. Luvic Gleysols occur commonly in poorly drained sites in association with Luvisolic soils and in depressions in areas of Black and Dark Gray Chernozemic soils.

Luvic Gleysols usually have an eluvial horizon (Ahe, Aeg) and a Btg horizon. A Btg horizon is defined on the basis of an increase in silicate clay over that in the A horizon, the presence of clay skins indicating illuvial clay, and colors and mottling as specified for the Gleysolic order indicative of permanent or periodic reduction. Luvic Gleysols may have an organic surface horizon and an Ah horizon. In some cases the A horizon is very dark colored (value of 2) when moist but its eluvial features usually are evident on drying. Such horizons usually have darker and lighter gray streaks and splotches similar to Ahe horizons of Dark Gray Chernozemic soils. Even if the eluvial horizon is dark in color, the Btg horizon is diagnostic of a Luvic Gleysol.

The great group is divided into five subgroups based on the kind and sequence of the horizons.

SOLONETZIC LUVIC GLEYSOL

Common horizon sequence: **LFH, or O, Ah, <u>Aeg</u>, <u>Bntg</u>, Cg**

These soils have the general properties specified for the Gleysolic order and the Luvic Gleysol great group. They have, in addition, a solonetzic B horizon. They may have Ah or Ap horizons as specified for Humic Luvic Gleysols. These soils are commonly associated with saline parent materials.

FRAGIC LUVIC GLEYSOL

Common horizon sequence: **LFH or O, Ah, <u>Aeg</u>, <u>Btgx</u>, Cg**

These soils have the general properties specified for the Gleysolic order and the Luvic Gleysol great group. They have, in addition, a fragipan within or below the Btg horizon. They may also have a dark-colored Ah or Ap horizon as specified for Humic Luvic Gleysols, Bgf or Btgf horizon as specified for Fera Luvic Gleysols. They do not have a solonetzic B horizon; such horizons are not known to occur in association with a fragipan.

HUMIC LUVIC GLEYSOL

Common horizon sequence: **LFH or O, <u>Ah</u>, Aeg, <u>Btg</u>, Cg**

These soils have the general properties specified for the Gleysolic order and the Luvic Gleysol great group. They have, in addition, a mineral-organic surface horizon that meets the requirements of the Ah or Ap horizon of Humic Gleysols. Thus, the Ah horizon must be at least 10 cm thick and the Ap horizon must be at least 15 cm thick, contain at least 2% organic C and be darker than the underlying horizon. Humic Luvic Gleysols do not have either a solonetzic B or a fragipan, but they may have a Bgf horizon.

FERA LUVIC GLEYSOL

Common horizon sequence: **LFH or O, Ah, <u>Aeg</u>, <u>Bgf</u>, <u>Btg</u>, Cg**

These soils have the general properties specified for the Gleysolic order and the Luvic Gleysol great group. They have, in addition, either a Bgf horizon at least 10 cm thick in addition to a Btg horizon, or a Btgf horizon. A Bgf or Btgf horizon contains an accumulation of hydrous iron oxide (dithionite exractable), which is thought to have been deposited as a result of the oxidation of ferrous iron. It usually has a high chroma and is commonly a horizon of concentration of rusty mottles. Fera Luvic Gleysols lack all of the following: an Ah or Ap horizon diagnostic of Humic Luvic Gleysols, a solonetzic B, and a fragipan.

ORTHIC LUVIC GLEYSOL

Common horizon sequence: **LFH or O, <u>Aeg</u>, <u>Btg</u>, Cg**

These soils have the general properties specified for the Gleysolic order and the Luvic Gleysol great group. Typically they have organic or mineral-organic surface horizons overlying gleyed, eluvial horizons, and a Btg horizon.

Orthic Luvic Gleysols are identified by the following properties:

1. They have an eluvial horizon: Ahe, Ae, Aeg.
2. They have a Btg horizon.
3. They do not have an Ah or Ap horizon as defined for Humic Gleysols and Humic Luvic Gleysols.
4. They lack a solonetzic B horizon, a fragipan and a Bgf horizon at least 10 cm thick.

HUMIC GLEYSOL

Soils of this great group have a dark-colored A horizon in addition to the general properties of soils of the Gleysolic order. They occur commonly in poorly drained positions in association with some Chernozemic, Luvisolic, Podzolic, and Brunisolic soils. They may have organic surface horizons derived from grass and sedge, moss, or forest vegetation.

Humic Gleysols have no Bt horizon, and they have either an Ah horizon at least 10 cm thick or a mixed surface horizon (Ap) at least 15 cm thick with all of the following properties:

1. More than 2% organic C.

2. A rubbed color value of 3.5 or less (moist), or 5.0 or less (dry).

3. At least 1.5 units of color value (moist) lower than that of the next underlying horizon if the color value (moist) of that horizon is 4 or more, or 1 unit of color value lower than that of the underlying horizon if its color value is less than 4.

Examples of color values of cultivated Humic Gleysols are:

	Example 1	Example 2
Moist color value of Ap	3.5 or less	2.0 or less
Moist color value of underlying horizon	5.0 or more	3.0 or more

The great group is divided into four subgroups based on the kind and sequence of the horizons. The former subgroup features turbic, placic, saline, carbonated, cryic, and lithic are now recognized taxonomically at either the family or series level. They may be indicated also as phases of subgroups, great groups, or orders.

SOLONETZIC HUMIC GLEYSOL

Common horizon sequence: **Ah**, **Bng**, **Cgsk**

These soils have the properties specified for the Gleysolic order and the Humic Gleysol great group. They have, in addition, a solonetzic B horizon and they may have a Bgf horizon. Typically they have saline parent materials.

FERA HUMIC GLEYSOL

Common horizon sequence: **LFH or O, <u>Ah</u>, Aeg, <u>Bgf</u>, Cg**

These soils have the general properties specified for the Gleysolic order and the Humic Gleysol great group. They have, in addition, a Bgf horizon at least 10 cm thick and they lack a solonetzic B horizon. The Bgf horizon contains an accumulation of hydrous iron oxide (dithionite extractable) thought to have been deposited as a result of the oxidation ferrous iron. Usually the Bgf horizon has many prominent mottles of high chromas.

ORTHIC HUMIC GLEYSOL

Common horizon sequence: **LFH OR O, <u>Ah</u>, <u>Bg</u>, Cg or C**

These soils have the general properties specified for the Gleysolic order and the Humic Gleysol great group. Typically they have a well-developed Ah horizon overlying gleyed B and C horizons. They may have organic surface horizons, an eluvial horizon, and a C horizon that does not have dull colors and mottling indicative of gleying.

Orthic Humic Gleysols are identified by the following properties:

1. They have an Ah horizon at least 10 cm thick as defined for the great group.

2. They have a B horizon, Bg or Bgtj at least 10 cm thick.

3. They do not have any of the following: a Btg horizon, a solonetzic B horizon or a Bgf horizon at least 10 cm thick.

REGO HUMIC GLEYSOL

Common horizon sequence: **LFH or O, <u>Ah</u>, <u>Cg</u>**

These soils have the general properties specified for the Gleysolic order and the Humic Gleysol great group. They differ from the Orthic Humic Gleysols by lacking a B horizon at least 10 cm thick. Typically they have a well-developed Ah horizon overlying a gleyed C horizon.

GLEYSOL

Soils of this great group have the general properties specified for soils of the Gleysolic order and they lack a well-developed, mineral-organic surface horizon. They occur commonly in poorly drained positions in association with soils of several other orders.

Gleysols lack an Ah or Ap horizon as specified for Humic Gleysols and a Bt horizon. They may have either an Ah horizon thinner than 10 cm or an Ap horizon with one of the following properties:

1. Less than 2% organic C.

2. A rubbed color value greater than 3.5 (moist) or greater than 5.0 (dry).

3. Little contrast in color value with the underlying layer (less than 1.5 units difference if the value of the underlying layer is 4 or more, or less than 1 unit difference if that value is less than 4).

They have a gleyed B or C horizon and they may have an organic surface horizon.

The great group is divided into four subgroups based on the kind and sequence of the horizons.

SOLONETZIC GLEYSOL

Common Horizon Sequence **Bng, Cgsk**

These soils have the general properties specified for the Gleysolic order and the Gleysol great group. They have, in addition, a solonetzic B horizon, and they may have a Bgf horizon. Typically they have saline parent material.

FERA GLEYSOL

Common horizon sequence: **LFH or O, Aeg, Bgf, Cg**

These soils have the general properties specified for the Gleysolic order and the Gleysol great group. They have, in addition, a Bgf horizon at least 10 cm thick and they lack a solonetzic B horizon. The Bgf horizon contains an accumulation of hydrous iron oxide (dithionite extractable), which is thought to have been deposited as a result of the oxidation of ferrous iron. Usually the Bgf horizon has many prominent mottles of high chroma.

ORTHIC GLEYSOL

Common horizon sequence: **LFH or O, Bg, Cg**

These soils have the general properties specified for the Gleysolic order and the Gleysol great group. Typically they have strongly gleyed B and C horizons, and they may have organic surface horizons and an eluvial horizon.

Orthic Gleysols are identified by the following properties:

1. They have a B horizon, Bg or Btjg at least 10 cm thick.

2. They may have an Ah or Ap horizon as specified for the Gleysol great group.

3. They do not have a Btg horizon, a solonetzic B horizon, or a Bgf horizon at least 10 cm thick.

REGO GLEYSOL

Common horizon sequence: **LFH or O, <u>Cg</u>**

These soils have the general properties specified for the Gleysolic order and the Gleysol great group. They differ from the Orthic Gleysols by lacking a B horizon at least 10 cm thick. Thus they consist of a gleyed C horizon with or without organic surface horizons and thin Ah or B horizon.

CONCLUSIONS

1. The report shows that the persistent problems associated with the classification of Gleysolic soils in Canada are due not only to the fact that soils in the landscape have a continuum of properties reflecting the prevailing oxidation-reduction conditions during their genesis, but also to differences among pedologists in concepts of soil classification. These concepts have evolved during the last half century but their development through the years and their consequences on the day by day use of soil taxonomy have not been documented (Michalyna and Rust, 1984a, b). An example of this is the concept held by some pedologists that Gleysolic soils must be poorly or very poorly drained. In fact, soils that developed for thousands of years under periodic or permanent high water tables and intermittent or prolonged reducing conditions may now not be saturated within the control section. These formerly poorly or very poorly drained soils may now be well or imperfectly drained but they may retain the gley features diagnostic of Gleysolic soils for years. Classifying such soils as Gleysolic and indicating their present water regime conveys more information than classifying them in another order so as to maintain consistency between present water regime and taxonomy. If the current water regime persists due to maintenance of drains or other factors, the soil will ultimately lose its pronounced gley properties and be appropriately classified in another order.

   Similarly, soils developed for thousands of years under well drained, oxidizing conditions may become saturated with water for prolonged periods due to damming of rivers or other causes. Such soils might be classified appropriately as Orthic Melanic Brunisols with aquic water regimes. In time, under such conditions, they would develop the features of Gleysolic soils and their classification would change accordingly.

   Another conceptual problem is inherited to a degree from the change from a field classification system (Stobbe, 1945), essentially a system of classifying map units, to a taxonomic system in which the taxa are conceptual and based on abstractions of properties of pedons (Stobbe, 1955; CSSC, 1978). Some pedologists still classify soils on the basis of their reading of the landscape, including slope position and vegetaion, rather than on the basis of properties of pedons. Ellis (1932) was well ahead of his time when he stated clearly more than half a century ago the need to classify soils on the basis of their properties.

2. Though color is not a soil property of major significance in itself, it remains the best known basis of criteria for differentiating Gleysolic soils. Other bases such as redox potentials, chemical properties and micromorphological features have been tried and research for a better basis should continue. Further fine tuning of color criteria in relation to thoroughly documented properties of different soil materials under different environmental conditions is necessary.

3. Further work is required to resolve problems that were set aside at the 1984 ECSS meeting (Tarnocai 1985). The most pressing of these are the classification of soils with chernozemic A underlain by gray, calcareous Aca or Cca horizons, and the limit between Humic Gleysols and Gleysols.

Proposals for the resolution of these problems were made (McKeague and Wang, 1985); it is now the responsibility of pedologists in areas where the problems are relevant to develop more suitable solutions and to test them.

4. Continuing assessment of Gleysolic order criteria will be necessary in the light of new information on soils from soil surveys, new information on soil properties in relation to soil climate and international developments in soil taxonomy. Relative to other soil problems, however, those involving aspects of Gleysolic soil classification are minor. The current requirement is to apply the system and to record thoroughly cases in which this results in apparently inappropriate classification of the soil.

ACKNOWLEDGEMENTS

We wish to thank the many pedologists from different regions of Canada who made us aware of inconsistencies in the present soil classification system (CSSC, 1978) and of problems in applying the criteria of Gleysolic soils to pedons in many areas, and who contributed through discussions and written material to the development of the points of view expreessed in this report. We thank, also, the staffs of the soil laboratories in Kelowna and in the LRRI, Ottawa for analyzing some of the soils discussed, and R.K. Guertin for preparing thin sections.

REFERENCES

Anderson, J.L. 1984. Soil mottling, an indicator of saturation. Soil Survey Horizons. 25(4):13-14.

Atkinson, H.J. 1971. A bibliography of Canadian soil science. Publ. 1452. Canada Department of Agriculture, Ottawa.

Avery, B.W. 1980. Soil classification for England and Wales. Soil Survey Technical Monograph No. 14. Harpenden.

Bloomfield, C. 1949. Gleying. Soils and Fertilizers. 12:1-3.

Bloomfield, C. 1951. Experiments on the mechanism of gley formation. J. Soil Sci. 2:196-210.

Bouma, J. 1983. Hydrology and soil genesis of soils with aquic moisture regimes. pp. 253-281 in Wilding, Smeck and Hall, eds. Pedogenesis and Soil Taxonomy. Vol. 1 Elsevier.

Brewer, R. 1964. Fabric and mineral analysis of soils. Krieger.

Brinkman, R. 1970. Ferrolysis, a hydromorphic soil forming process. Geoderma 3:199-206.

Canada Department of Agriculture. 1970. The system of soil classification for Canada. Queen's Printer, Ottawa.

Canada Soil Survey Committee. 1978. The Canadian system of soil classification. Can. Dep. Agric. Publ. 1646. Supply and Services Canada.

Childs, C.W. 1981. Field tests for ferrous iron and ferric-organic complexes on exchange sites or in water-soluble forms in soils. Aust. J. Soil Res. 19:175-180.

Crown, P.H. and Hoffman, D.W. 1970. Relationship between water table levels and type of mottles in four Ontario Gleysols. Can. J. Soil Sci. 50: 453-455.

Day, J.H. ed. 1979. Minutes, first annual meeting Expert Committee on Soil survey. Ottawa.

Ibid. 1980. Second meeting.

Ibid. 1981. Third meeting.

Day, J.H. (ed.) 1983. Manual for describing soils in the field. Agriculture Canada, Ottawa.

DeKimpe, C.R., McKeague, J.A. and Topp, G.C. 1974. Soil properties in relation to water regime at a site near Quebec city. Can. J. Soil Sci. 54: 427-446.

Duchaufour, P. 1982. Pedology. Transl. from French by T.R. Paton George Allen and Unwin.

Ehrlich, W.A. 1958. Report on classification of Gleysolic soils. pp. 33-36 in Report Western Section, NSSC, Edmonton.

Ehrlich, W.A. 1960. Report on the classification of Gleysolic soils. pp. 30-33 in Report NSSC, Guelph.

Ehrlich, W.A. 1963. Report on the classification of Gleysolic soils. pp. 49-53 in Report 5th Meeting NSSC, Winnipeg.

Ehrlich, W.A. 1965. Report on the classification of Gleysolic soils. pp. 60-64 in Proc. 6th Meeting, N.S.S.C., Quebec.

Eilers, R.G. 1973. Relations between hydrogeology and soil characteristics near Deloraine, Manitoba. M.Sc. Thesis, Univ. of Manitoba. 202 pp.

Ellis, J.H. 1932. A field classification of soils for use in soil survey. Sci. Agr. 12: 338-345.

FAO - UNESCO. 1974. Soil map of the world. Vol. 1, Legend, Unesco, Paris.

Franzmeier, D.P., Jahner, J.E., Steinhardt, G.C., Sinclair, H.R. Jr. 1983. Color patterns and water table levels in some Indiana soils. Soil Sci. Soc. Am. J. 47:1196-1202.

Ignatieff, V. 1939. Method of determining ferrous iron in soil solutions and a study of the effect of light on the reduction of iron by citrate and 2:2' dipyridyl. J. Soc. Chem. Ind. Trans. 56:407-410.

Igntieff, V. 1941. Ferrous iron in soils. Soil Sci. 54:249-263.

Joffe, J.S. 1936. Pedology. Rutgers University Press.

Mackintosh, E.E. 1973. Report of the subcommittee on soil water regime. pp. 136-153 in Proc. 9th Meeting CSSC, Saskatoon.

Mackintosh, E.E. 1976. Report of the Subcommittee 4; Soil water regimes. pp. 27-37 in Selected Proc. 11th Meeting CSSC, Guelph, K.W.G. Valentine, ed.

Mackintosh, E.E. and Van der Hulst, J. 1978. Soil drainage classes and soil water table relations in medium and coarse textured soils of southern Ontario. Can. J. Soil Sci. 58:287-301.

Macyk, T.M., Pawluk, S. and Lindsay, J.D. 1978. Relief and microclimate as related to soil properties. Can. J. Soil Sci. 58: 421-438.

Matthews, B.C. 1963. Report on soil moisture. pp. 64-65 in Report 5th Meeting NSSC, Winnipeg.

McKeague, J.A. 1958. A study of some Alberta soils under different drainage conditions. M.Sc. Thesis. Univ. of Alberta, 106 pp.

McKeague, J.A. 1965a. Relationship of water table and Eh to properties of three clay soils in the Ottawa Valley. Can. J. Soil Sci. 45: 49-62.

McKeague, J.A. 1965b. Properties and genesis of three members of the Uplands catena. Can. J. Soil Sci. 45: 63-77.

McKeague, J.A. 1965c. A laboratory study of gleying. Can. J. Soil Sci. 45: 199-206.

McKeague, J.A. 1968. Report of the subcommittee on the classification of Gleysolic soils. pp. 71-76 <u>in</u> Proc. 7th Meeting NSSC, Edmonton.

McKeague, J.A. 1970. Report on Gleysolic soils. pp. 129-131 <u>in</u> Proc. 8th Meeting CSSC, Ottawa.

McKeague, J.A. 1970. Report of the subcommittee on soil moisture regimes. pp. 9-20 <u>in</u> Proc. 8th Meeting CSSC, Ottawa.

McKeague, J.A. and Bentley, C.F. 1960. The effect of drainage conditions on the redox potential, leachate composition and morphological characteristics of a soil parent material studied in the laboratory. Can. J. Soil Sci. 40: 121-129.

McKeague, J.A., Luttmerding, H.A. and Tarnocai, C. 1985. Gleysolic order criteria applied to five pedons from British Columbia. Can. J. Soil Sci. (in press).

McKeague, J.A., Nowland, J.L., Brydon, J.E. and Miles, N.M. 1971. Characterization and classification of five soils from eastern Canada having prominently mottled B horizons. Can. J. Soil Sci. 51: 483-497.

McKeague, J.A. and Wang, C. 1985. Proposal of improved criteria for Gleysolic soils. pp. in J.A. Shields and D.J. Kroetsch, eds. Proc. 6th Meet. Expert Committee on Soil Survey.

Michalyna, W. 1971. Distribution of various forms of aluminun, iron, and manganese in the Orthic Gray Wooded, Gleyed Orthic Gray Wooded and related Gleysolic soils in Manitoba. Can. J. Soil Sci. 51: 23-36.

Michalyna, W. 1974. Influence of drainage regime on the chemistry and morphology of Chernozemic soils in Manitoba. Ph.D. Thesis. Univ. of Minn. 209 pp.

Michalyna, W. and Rust, R.H. 1984a. Influence of drainage regime on the chemistry and morphology of some Maniltoba soils: Sandy Chernozemic and Gleysolic soils of the lower Assiniboine Delta. Can. J. Soil Sci. 64:587-604.

Ibid. 1984b. Clayey Chernozemic and Gleysolic soils of the Red River Plain. Can. J. Soil Sci. 64:605-620.

Miller, J.J. 1983. Hydrology of a morainic landscape near St. Denis, Saskatchewan, in relation to the genesis, classification and distribution of soils. M.Sc. Thesis, University of Saskatchewan, Saskatoon.

Mückenhausen, E. 1963. Le pseudogley. Sci. du Sol. 1:1-8.

Mückenhausen, E. 1965. The soil classification system of the Federal Republic of Germany. Pédologie. Intern. Symp. 3, Soil Classification, Ghent. p.57-74.

Murphy, C.P. 1984. The morphology and genesis of eight surface-water gley soils developed in till in England and Wales. J. Soil Sci. 35:251-272.

Murphy, C.P. and Bullock, P.,eds. 1981. International working-meeting on soil micromorphology. Programme and guide for post-meeting excursion through England and Wales. Rothamsted Experimental Station.

Nowland, J.L. 1981. Soil water regime classification. 1981. pp. 64-74 in Proc. 3rd Meeting ECSS, J.H. Day, ed., Ottawa.

Pickering, E.W. and Veneman, P.L.M. 1984. Moisture regimes and morphological characteristics in a hydrosequence in central Massachusetts. Soil Sci. Soc. Am. J. 48:113-118.

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96.

Richardson, J.L. and Hole, F.D. 1979. Mottling and iron distribution in a Glossoboralf-Haplaquoll hydrosequence on a glacial moraine in northwestern Wisconsin. Soil Sci. Soc. Am. J. 43:552-558.

Ruhnke, G.N. 1926. The soil survey of southern Ontario. Sci. Agric. 7:117-124.

Schlichting, E. and Schwertmann, U. 1973. Pseudogley and gley. Verlag Chemie.

Shields, J.A. and Kroetsch, D.J. 1985. Proc. 6th Annual meeting, Expert Committee on Soil Survey, Guelph. Agr. Can., Ottawa.

Siuta, J. 1967. Gleying as an indicator of the water and air regime of a soil. Soviet Soil Sci. No. 3:356-363.

Smith, R.E. 1973. Report of the subcommittee on Gleysolic soils. pp. 309-320 in J.H. Day and P.G. Lajoie, eds. Proc. 9th Meet. Canada Soil Survey Committee. Agriculture Canada, Ottawa.

Soil Survey Staff. 1975. Soil taxonomy. U.S. Dept. Agr. Handbook, No. 436. U.S. Gov't. Printing Office, Washington, D.C.

Stobbe, P.C. 1945. The report of the sub-committee on soil classification. pp. 20-42 in Proc. First Conf. National Soil Survey Committee, Ottawa.

Stobbe, P.C. 1955. Report of the sub-committee on soil classification. pp. 20-42 in Report Third Conf. National Soil Survey Committee.

Stonehouse, H.B. and St. Arnaud, R.J. 1971. Distribution of iron, clay and extractable iron and aluminum in some Saskatchewan soils. Can. J. Soil Sci. 51, 283-292.

Tarnocai, C. 1985. Report of the sub-committee on soil classification. pp. in J.A. Shields (ed.). Proc. 6th Annual meeting, Expert Committee on Soil Survey, Guelph. Agr. Can., Ottawa.

Thomasson, A.J. 1973. Factors influencing the water regimes of gleyed clayey soils in moist temperate regions. pp. 491-502 in Gley and Pseudogley, E. Schlichting and V. Schwertmann, eds. Verlag-Chimie.

Thorp, J. and Smith, G.D. 1949. Higher categories of soil classification: order, suborder and great soil group. Soil Sci. 67:117-126.

Veneman, P.L.M. and Bodine, S.M. 1982. Chemical and morphological soil characteristics in a New England drainage toposequence. Soil Sci. Soc. Am. J. 46:359-363.

Vepraskas, M.J. and Wilding, L.P. 1983a. Aquic moisture regimes in soils with and without low chroma colors. Soil Sci. Soc. Am. J. 47:280-285.

Ibid. 1983b. Albic neoskeletans in argillic horizons as indices of seasonal saturation and iron reduction. Soil Sci. Soc. Am. J. 47:1201-1208.

Zaydel'man, F.R. 1984. Principles and draft of a classification of mineral soils in humid areas according to degree of hydromorphism and water-logging. Soviet Soil Sci. 16:72-81.

Zobeck, T.M. and Ritchie, A. Jr. 1984. Analysis of long-term water table depth records from a hydrosequence of soils in central Ohio. Soil Sci. Soc. Am. J. 48:119-125.

Zoltai, S.C. and Tarnocai, C. 1974. Soils and vegetation of hummocky terrain. Environmental-Social Program, Northern Pipelines. Report No. 74-5.

Canadä